

# ***Cold Atom Laboratory***

***Exploring the Quantum Universe One Atom at a Time***



## **CAL Status**

Robert Shotwell

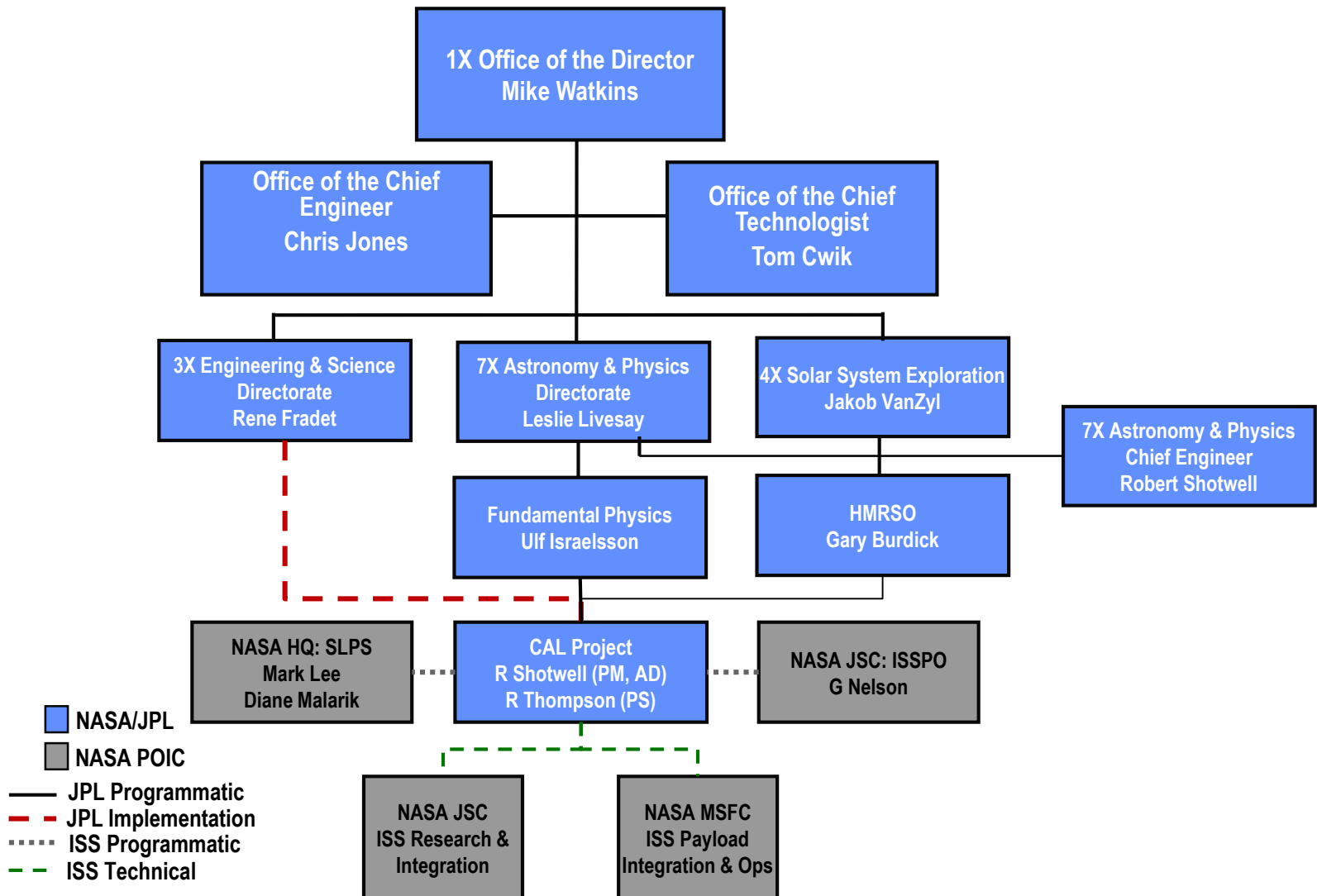
Project Manager

Jet Propulsion Laboratory, California Institute of Technology

Wednesday May 31, 2017



# Jet Propulsion Laboratory Organization





# Shotwell Background



- I have been the Chief Engineer for Astronomy and Physics since Feb of 2016
- Prior to that I was
  - Chief Engineer NASA Mars Program (2 yrs)
  - Program Engineer JPL reimbursable programs (DOD, etc, 6 years)
  - Project Systems Engineer Phoenix Lander (2003-2008)
  - Advanced Propulsion R&D (ion engines, hall thrusters, magnetoplasmadynamic thrusters, etc, ~2 yrs)
  - Lead flight engineer Deep Space 1 Ion Engine propulsion system (~ 3 yrs)
  - Propulsion engineer Mars Pathfinder (~ 3 yrs)
- CAL is an additional duty assignment to get the flight system completed, tested and delivered
- CAL is an exciting physics instrument and am happy to be able to help contribute to its success!

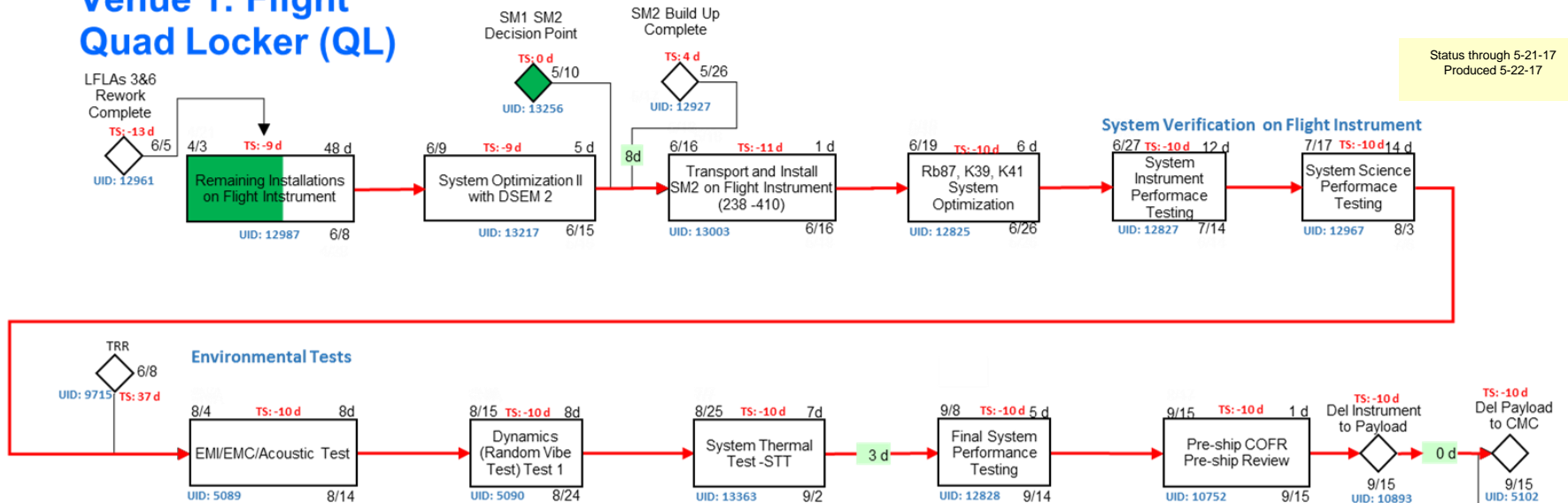


# CAL Status

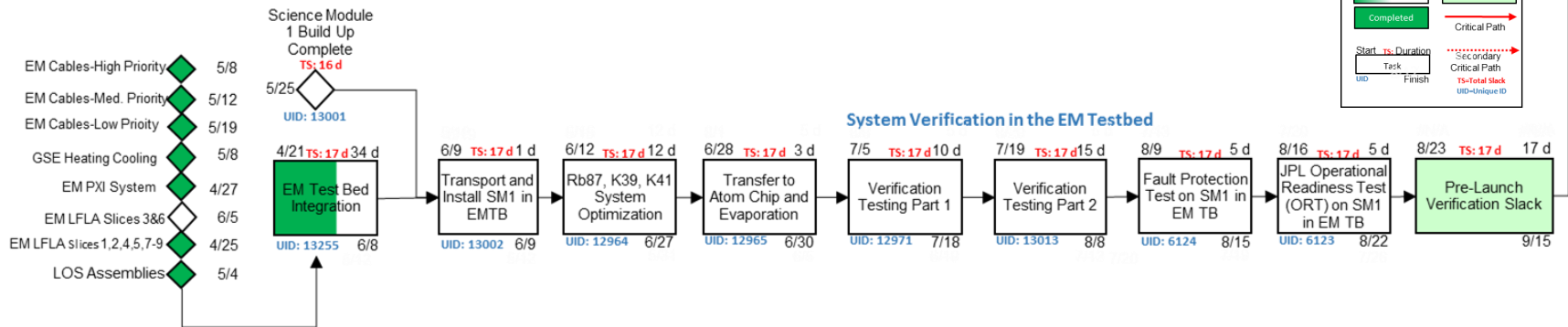


- CAL is working to an Aug 31 Flight Hardware Availability (FHA) date
  - Renegotiated from April delivery
  - Potentially to be flown on SpaceX 13 in November (to be confirmed)
- CAL was replanned and rescope to meet the new delivery date, with appropriate development and testing addressed
  - Approved liens with sponsors completed
  - Schedule reworked to reflect achievable milestones and delivery points
- CAL is now building a full Engineering Model (EM) testbed
  - Replicate flight system
  - For use in flight system design verification
  - For use in operations and flight sequence validation
- CAL has gotten approval to build a 2<sup>nd</sup> Science Module based on CAL 2A physics package
  - Utility chip based, also expected for Atom Interferometry ORU build
  - Will be the Flight Unit – Seeing excellent performance to date!
- Science Module 1 based on CAL 1A also reworked and completed
  - CAL 1A atom chip is cracked, and has suspect reliability
  - Will be installed in EM TB for verification and operations

## Venue 1: Flight Quad Locker (QL)

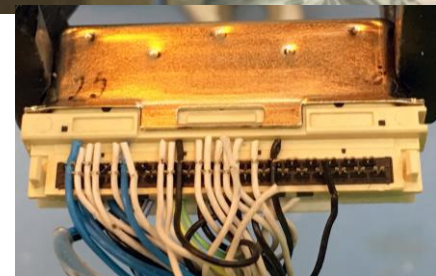
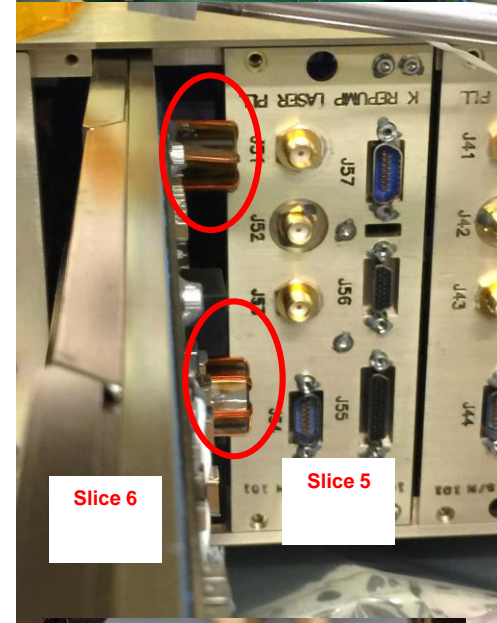
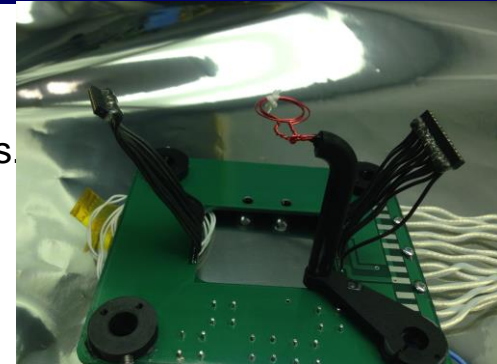


## Venue 2: EM Test Bed



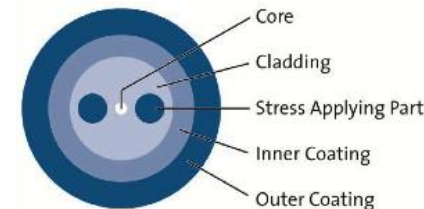
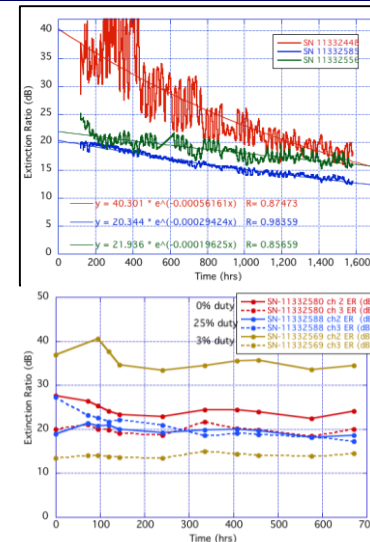
# Some CAL Key Challenges

- Physics Package
  - Breakout Board Rework of PP CAL-1A, 2A, & 1B to replace PCB connector and cable that were found to have failed soldered connections.
- Electronic Hardware
  - AWG has unique idiosyncrasy verified by NI, using operational workaround
  - Master Lock noise issues preventing reaching <1 Mhz linewidth (currently ~ 1.5 Mhz Rb) – Tiger Team established to look for technical resolution
    - Potassium performance is at risk
  - Slices have physical interference fit and must be installed in specific arrangements, and retain tight clearances
  - Some loop gains have required parts changes, boards have been damaged from excessive rework
  - Failed converters had to be replaced
  - Line driver circuits added to numerous PXI drivers
- Cabling
  - Initial set of cables developed from out of date dwgs, had to be remade
  - Cabling had many grounding and shielding design issues
  - Cabling had sensitive power, signal and comms lines wrapped together, creating cross talk and signal corruption
  - Connectors were not flight like and had to be modified for reliability



- Laser Optical Systems

- Agiltron switches were seeing significant degradation over time
  - Custom Switches had little to no vendor data
  - Extinction ratio inadequate for required lifetime (wound up doubling some of the key ones to make robust)
- Leoni switches required repackaging from vendor
- Precision Fiber Connectors not properly centroided and were getting several dB loss resulting in inadequate delivered laser powers
  - All had to be reterminated
- Fiber optic contamination issues drove new procedures for cleaning and prep
- Polarization not well tracked and connectors not properly aligned resulting in PER instability and power losses
- COTS imaging systems had loose set screws and unverified coatings, different geometries

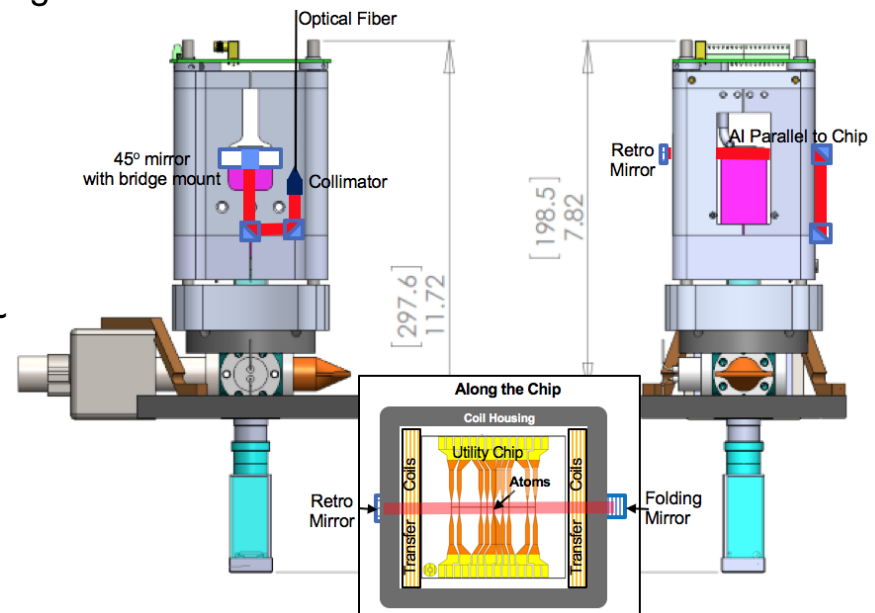


- Software was initially written by several different people with different approaches and not a common architecture
  - Much of it is being re-written as we speak
  - A lot of functionality for high speed controls was put into SW instead of HW (digitization introduces a lot of additional problems)



# Atom Interferometry

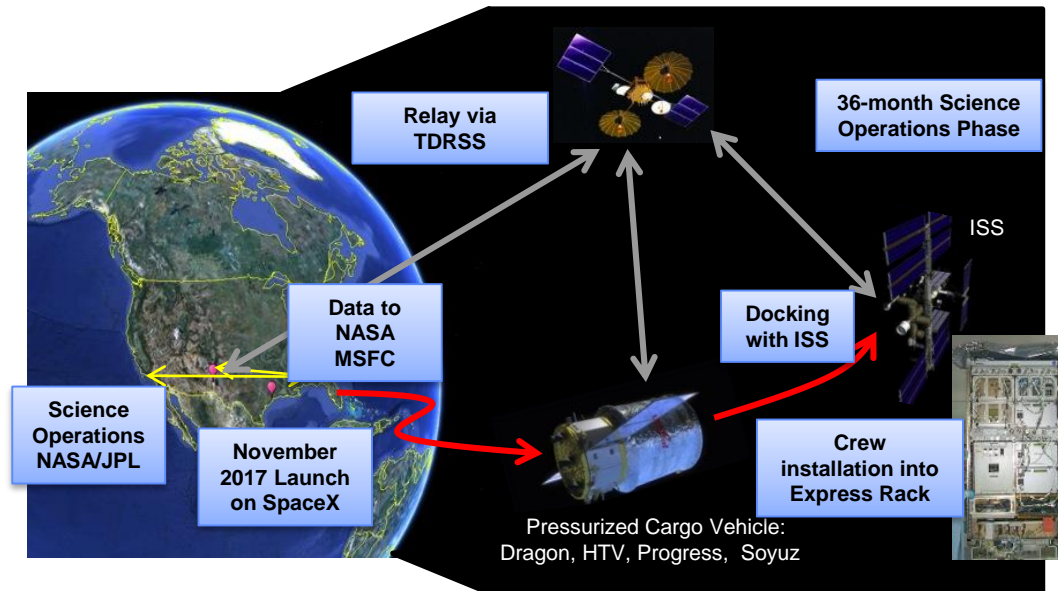
- CAL First Flight Unit will not have AI
  - Unable to make AI capable physics package work reliably in time for delivery
- Sponsor has agreed to let AI get installed as an **ORU** in the next year
  - There are many experiments over the next year that don't require AI
- Current plan is to develop a flight worthy AI physics package starting this summer when CAL flight system starts environments
  - Will free up some time for science and engineering team to focus on optomechanical design
  - Current plan is to use Utility chip based physics package and develop a horizontal AI system (original concept was vertical and used windows introduced in CAL specific chipset)
  - Initial development will use CAL 1B physics package to breadboard
  - New PP will be used for flight AI system
- Flight AI ORU is not currently funded
  - A soft lien has been entered into ISS reserve tracking system for awareness
  - Decision to release reserve for this expected in ~ Sept once end of year assessment complete
  - Funding is not guaranteed and may be at risk if CAL development continues to have issues or slips further to the right



Conceptual design of Horizontal AI approach



## CAL ISS Utilization



### Checkout Phase

Remote operations from JPL with **real-time** uplinks and downlinks.  
**6 weeks**

### Validation Phase

Remote operations from JPL with **real-time** uplinks and downlinks.  
**6 weeks**

### Science Ops Phase

CAL will be operated for at most 8 hours per day, during crew sleep.  
**36 months**

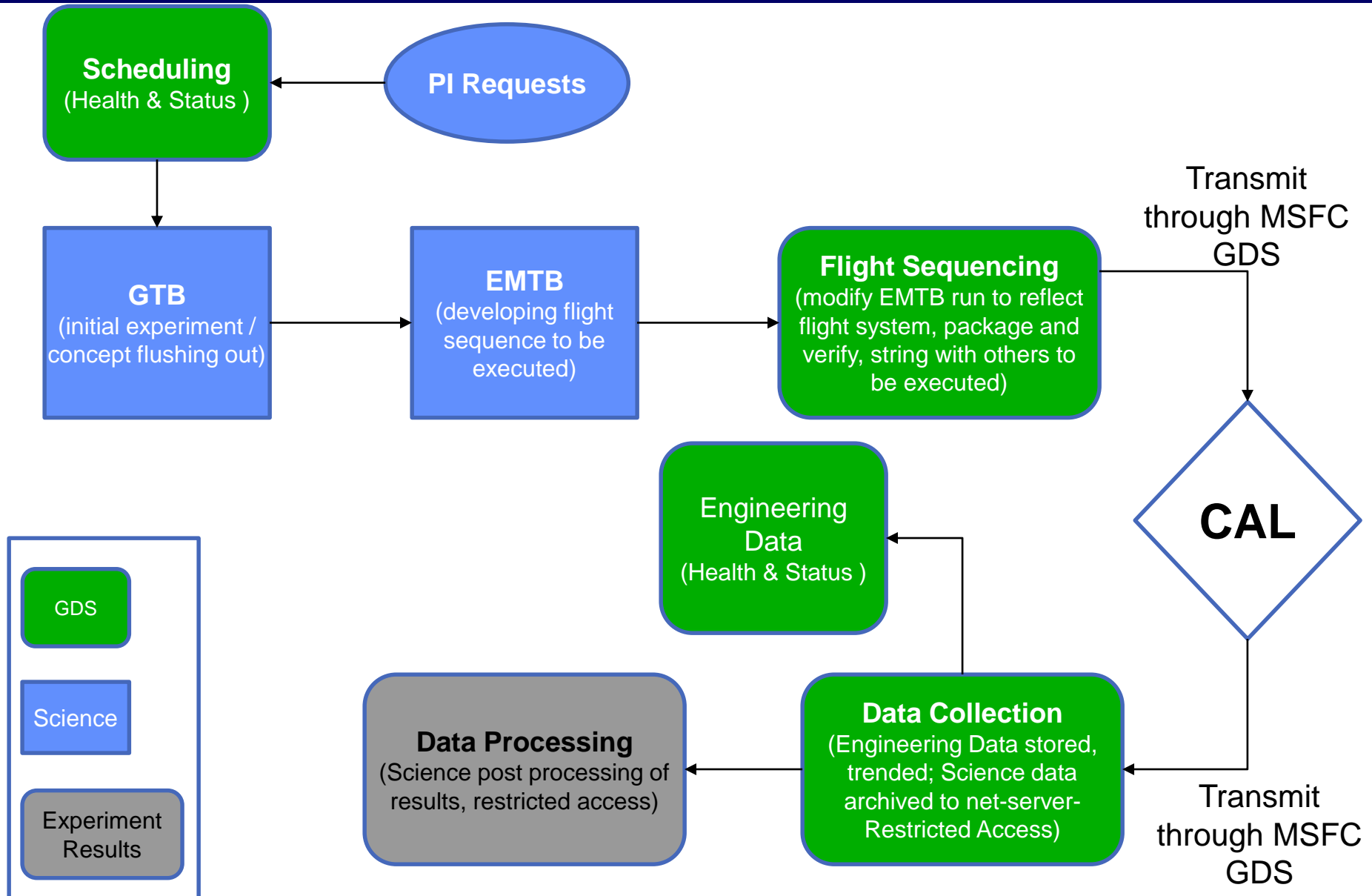
### ORU

Operational Replacement Units (ORUs) would be used to meet  
**3 year mission life**

### SM ORU

Science Module with Atom Interferometer (AI) ORU is planned to be delivered to ISS  
**15 months** after launch

- The Mission and Science Operations Center will be located at JPL, in Building 264. The Mission and Science Operations Center will include a Ground Data system and the Post Processing System.
- Communication to/from the CAL instrument and the ground will be through Huntsville Operations Support Center at Marshall Space Flight Center.
- CAL will nominally be remotely operated from JPL for 8 hours/day during crew sleep. The CAL primary mission will begin with installation by the ISS crew, followed by checkout, validation, and science operations phases.



TimeOutSec  
0

TLmax  
0

Run\_Time  
0

MotActive

PauseAck

ADC Sampling

StepOut  
0

AT1

AD1

AZ1

AD2

DSPK

DSPRb

Z Xfer

BX1

BY

BZ

AWG

gTrig

Cam

mShut

OpSw

Temperature (Degree C)  
0.0

Current (A)  
0.000

0% Current

ATOM Z1

ATOM D1

ATOM Z2

ATOM D2

DISP K

DISP Rb

Z Xfer

BIAS X1

BIAS X2

BIAS Y

BIAS Z

Output Enable  
AZ1 AD1 AZ2 AD2 DSPK DSPRb Z Xfer BX1 BX2 BY BZ AWG gTrig Cam mShut OpSw

Pause Delay  
0

Pause/UnPause

Load Table

Reset FPGA

Save Table

Process Table

Telemetry Off?

Stop Button  
Stop

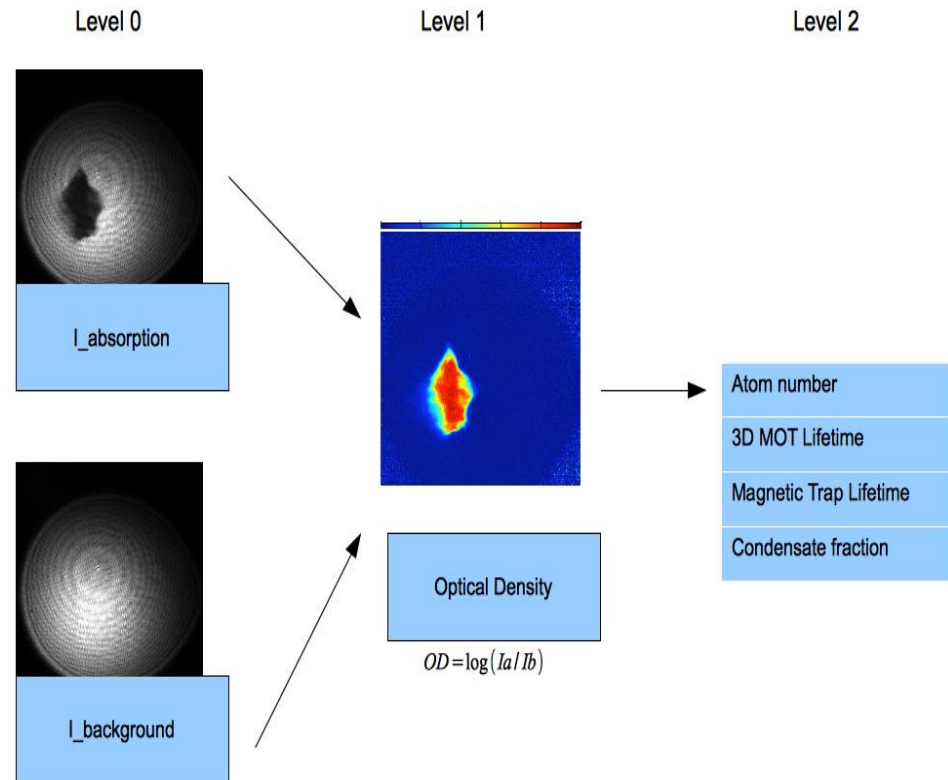
CamPulseWidth  
0

MechShutWidth  
0

OpticalSwitchWidth  
0

- Configuration files are uplinked daily and describe experiment parameters that must be controlled with precision timing, such as stage lengths, magnetic coil current, laser frequency, and pulse duration.
- Each experiment is about 1 minute in duration and is composed of several stages.
- A partial prototype interface for configuration files is shown.
- Each row represents an experiment stage. Each column represents a particular parameter that can be varied.

- Level 0 data will include raw science image data and associated metadata. Science raw data will consist of images of the atoms in Bose-Einstein Condensate (BEC) form.
- Level 0 to Level 1 processing will include computation of optical density from three types of images: absorption, background, and reference images.
- Level 1 to Level 2 processing will include the following products:
  - 3D MOT lifetime
  - Magnetic chip trap lifetime
  - Atom Number, including associated Gaussian fitting, cropping, atom density, cloud size
  - Condensate fraction





**BACKUP**



# CAL Organizational Chart - Phase D

